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Tumbler Ridge Branch Line Electrification Demonstration

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TUMBLER RIDGE BRANCH LINE ELECTRIFICATION DEMONSTRATION

by

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BC Rail Ltd.

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17. Abstract

BC Rail's Tumbler Ridge Branch Line was built between 1981 and 1983 to provide rail access to the north-east coal fields in British Columbia. Because of long grades and heavy tonnages, it was decided to electrify the branch line rather than provide complex ventilation systems in the two long tunnels. This report documents the reasons for electrification, the design, construction and commissioning of the power supply and catenary systems, the testing of the electric locomotives, power management and operating and maintenance costs.

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17. Résumé

Le tronçon de voie ferrée Tumbler Ridge de BC Rail a été construit entre 1981 et 1983 afin de fournir un accès ferroviaire aux gisements de charbon du nord-est de la Colombie-Britannique. Vu les longues pentes et le lourd tonnage, il a été décidé d'électrifier le tronçon plutôt que d'avoir à installer des systèmes complexes de ventilation dans les deux longs tunnels. Ce rapport documente les raisons de l'électrification, l'élaboration, la construction et la mise en service des systèmes d'alimentation et de caténaires, les essais des locomotives électriques, la gestion de puissance et les coûts d'opération et d'entretien.

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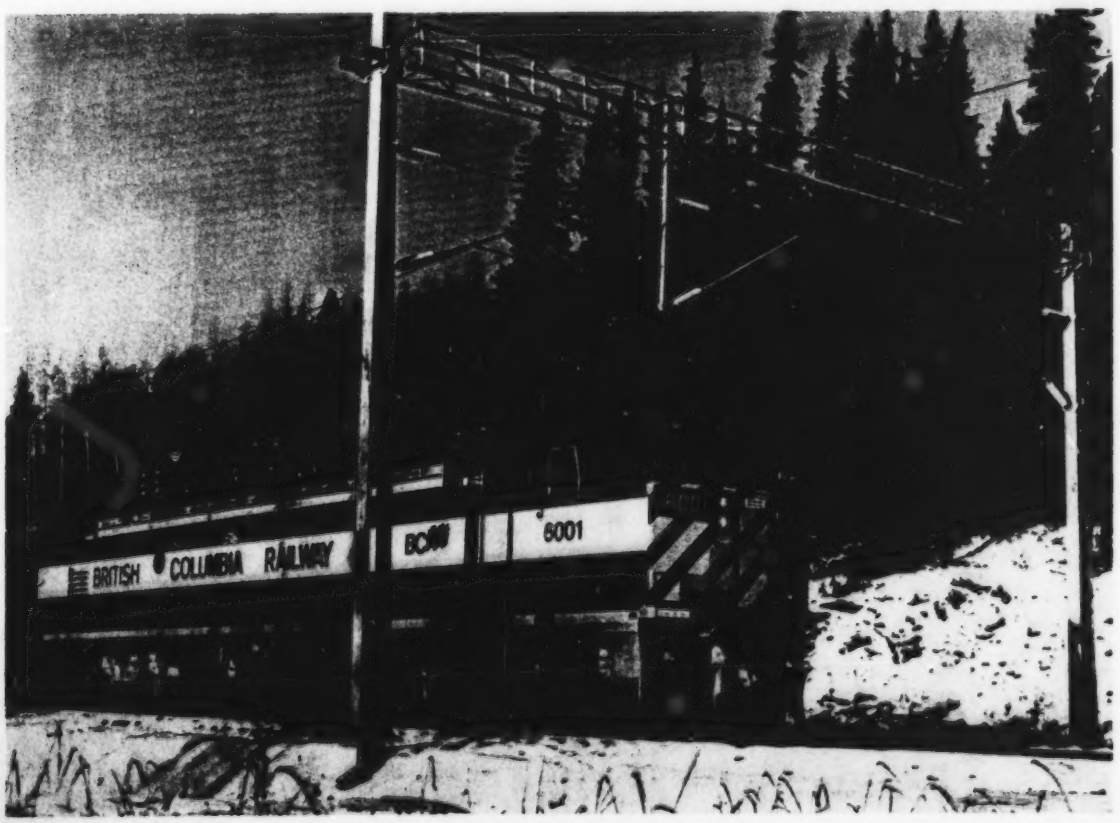

1. INTRODUCTION

In 1976, British Columbia Railway was requested to carry out feasibility studies for rail access into the coal fields of northeastern British Columbia. These coal fields held vast quantities of high-grade metallurgical coal with excellent market potential. Further feasibility studies in 1980 concluded that a 130 km branch line could be built from Anzac on the BC Rail main line into the coal fields for an estimated $310 million (1980 dollars).

When agreement in principle was reached for the purchase of coal by the Japanese steel industry in December 1980, the design and construction of the Tumbler Ridge Branch Line was initiated. The call for tenders for the first 30 km of grade was based on the data collected in the feasibility studies. Construction commenced in July 1981 in the western half of the project. Work on the first 19 km in the eastern half began in October 1981 and on the remaining 33 km in June 1982. Grading work was completed by September 1983.

Concurrent with the grade construction was the excavation of two short tunnels and two longer tunnels (the 6 km Wolverine Tunnel and the 9 km Table Tunnel). Material excavated from the longer tunnels was used as fill for the local railway roadbed. All tunnel work was completed by October 1983.

Prompted by concern over ventilation requirements in the Wolverine Tunnel and Table Tunnel and by the availability of provincial and federal government grants, it was decided that the Tumbler Ridge Branch Line should be put into full electric operation. This meant that the tunnel ventilation systems, with their chimneys, fans and control gates, could be dispensed with.

Design of the electrification system commenced in June 1982 and all material purchases were completed by May 1983. Contracts were tendered for the installation of the electrical substation, the capacitor station and the catenary system in May 1983 and construction was largely completed by November 1983. Coal trains powered by electric locomotives began operating on schedule in December 1983.

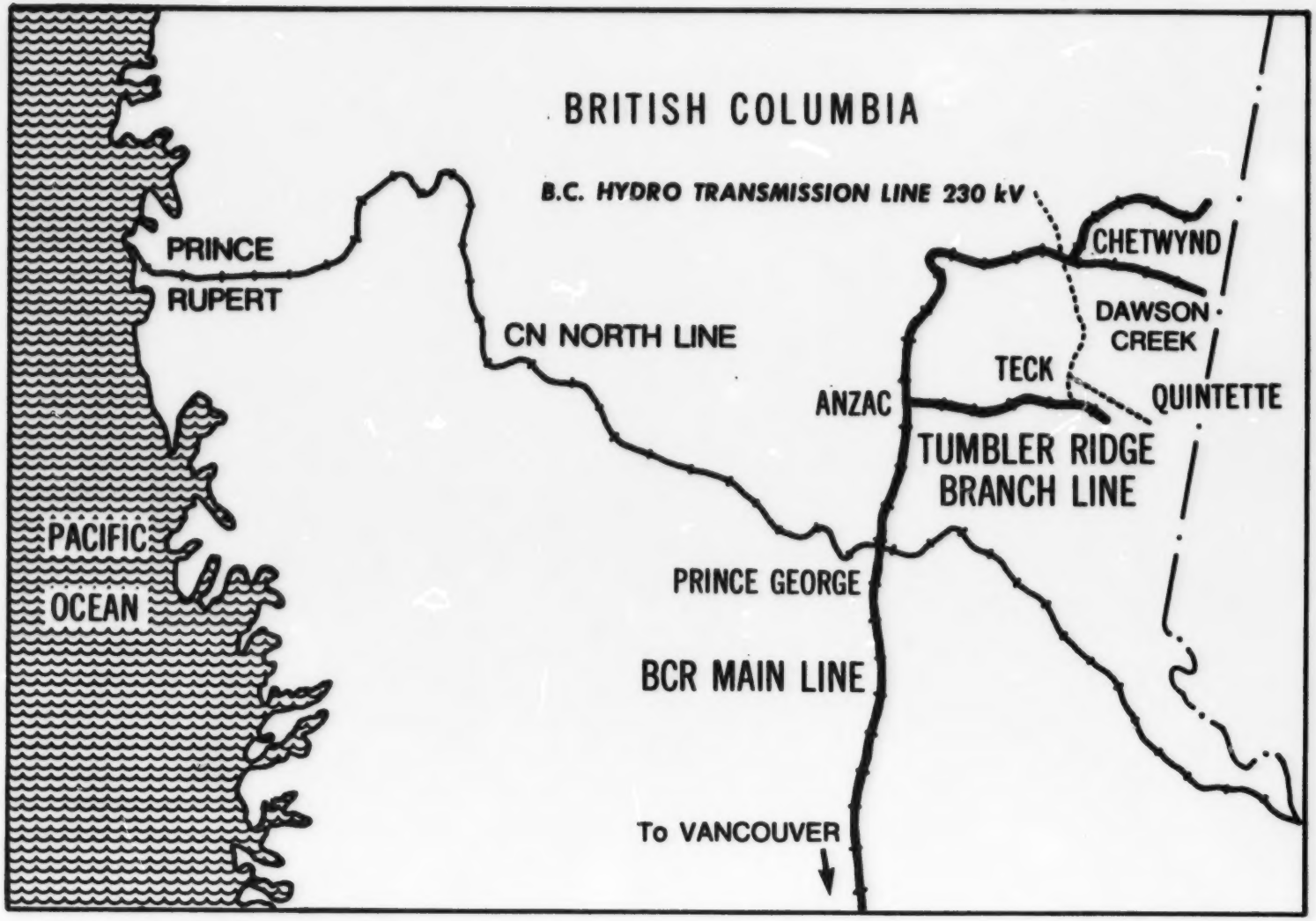

Figure 1 BC Rail Main Line and Tumbler Ridge Branch Line

2. JUSTIFICATION FOR ELECTRIFIED OPERATION

In order to justify a project of this magnitude, two principal cost centres relating to conventional diesel operation were reviewed. These were the cost of purchasing diesel fuel and the cost of providing and operating a complex ventilation system in the two longer tunnels. The economic analysis of these factors was very much site-specific, owing to the grades and tunnels involved. Also taken into consideration was the funding available from the Transportation Development Centre and the federal/provincial conservation and renewable energy programs.

The two principal energy-related benefits of using electricity on the Tumbler Ridge Branch Line were seen to be: the consumption of less energy to move coal from the mines to the BC Rail main line and the use of a renewable energy source rather than a non-renewable fossil fuel. Based on a BC Rail study carried out in 1982, it was calculated that electric locomotives use 37% of the energy consumed by conventional diesel locomotives of similar horsepower. A diesel locomotive consist was estimated to use 9,330 litres of high-grade diesel fuel on each round trip, while an electric locomotive consist would use 37 MW·h of electricity. This converts to 360 GJ of diesel energy and 133 GJ of electrical energy, or a ratio of 37%. Based on the expected annual maximum of 953 round trips from 1986 onwards and on energy costs in late 1982, it was estimated that energy savings alone would amount to $729,000 each year.

Other savings would be gained from reduced locomotive maintenance and elimination of tunnel ventilation systems. Partially offsetting these savings would be the cost of maintaining the substation and the overhead contact system. The net annual savings were estimated to be in the order of $1,535,000. The actual savings are greater, as discussed in section 7.

Electrified rail operations were also seen to offer environmental advantages: electric locomotives are cleaner and quieter to operate than diesel locomotives and, with no exhaust gases, provide a much safer environment for crews in long tunnels.

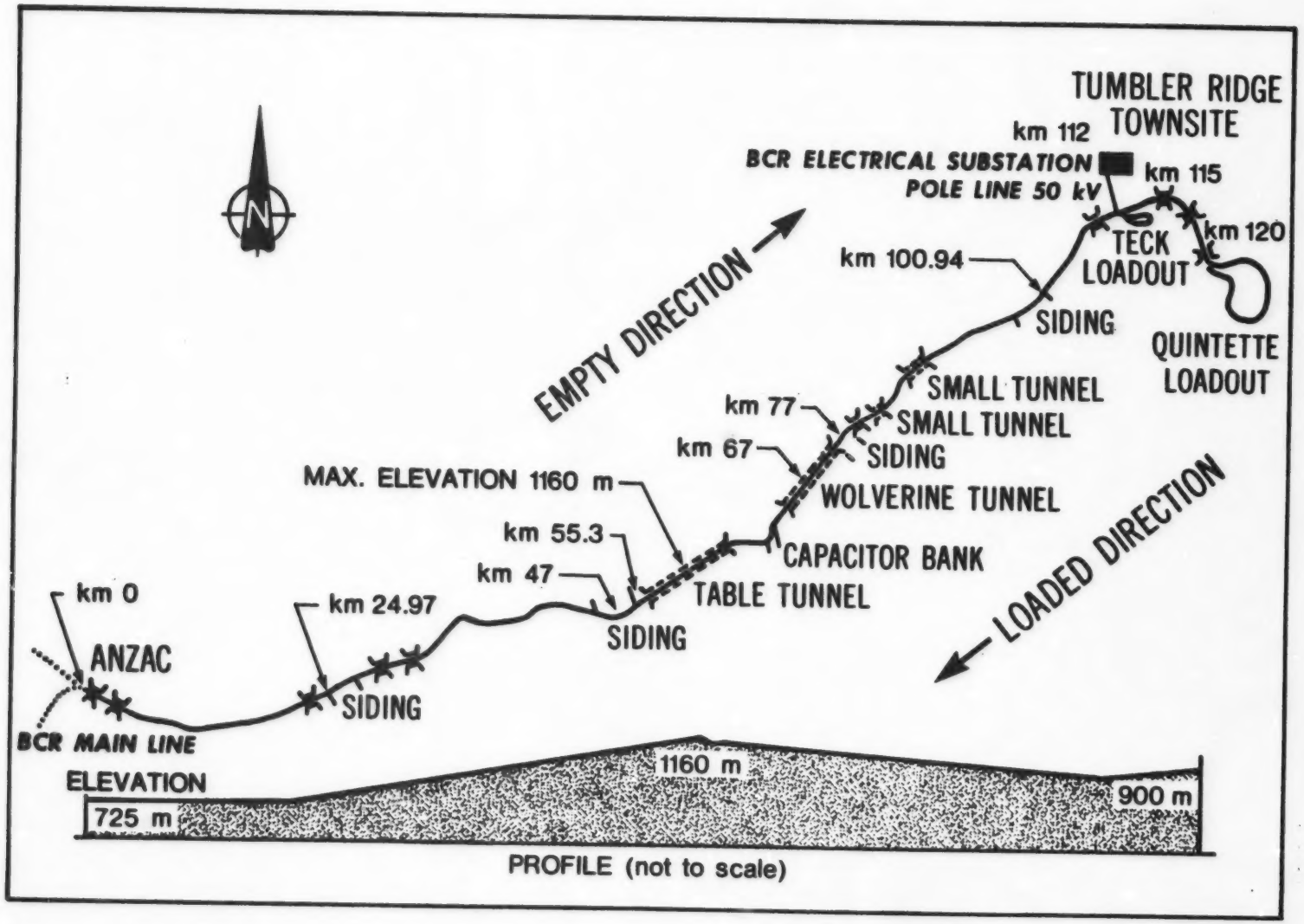

Figure 2 Tumbler Subdivision

3. DESIGN AND CONSTRUCTION

3.1 Description of the System

In May 1982, BC Rail began taking the necessary steps for formal ratification of the project by the provincial and federal governments. An immediate start was made to acquire key components (new locomotives, main power transformers) and the Canadian manufacturing rights to the Swedish catenary hardware selected.

A conceptual design study was conducted to analyze the options of partial and full electrification. It was decided that the system would be fully electrified using a single 230/50 kV substation that would be built adjacent to the B.C. Hydro substation at Tumbler Ridge and a 2 km, 50 kV feeder from the substation to transmit power to the catenary system.

The substation has two 230/50 kV single-phase transformers rated at 25/33 MVA. Each transformer is large enough to supply the full demand of the system. Protective relaying for the electrified system is located in the substation. Remote control, status monitoring and telemetering of the substation, series capacitor station, harmonic filter station and sectionalizing catenary disconnects are provided via a microwave system and microcomputer-based supervisory, control and data acquisition (SCADA) system based at BC Rail's head office in North Vancouver.

The catenary system is of the "simple catenary" design, using a 4/0 solid copper contact wire suspended from a 2/0 stranded messenger wire. This system is capable of maintaining contact with trains travelling at speeds of up to 100 km/h. A feeder line of 107 mm^2 ACSR stranded conductor on the poles parallels the contact system. The electrical return consists of 107 mm^2 ACSR stranded conductor, the continuous welded rail and the earth.

The catenary is divided into sections along its entire length. Each section, approximately 25 km long, can be isolated by a motor operated disconnect controlled by the SCADA system. This permits the load-out loops to remain operational while the main line is taken out of service.

The electric locomotives are type GF6C built by General Motors of Canada. Each locomotive has a continuously rated power of 3800 kW, equivalent to a maximum diesel horsepower of 6000 hp. Each traction motor is separately excited and is controlled by a wheel slip system that maintains wheel creep at a preset level and permits sustained adhesion levels in excess of 23% in all operating conditions and with minimal sand usage.

3.2 Substation and Capacitor Station

Preparation of the substation site at km 112 was performed concurrently with grade construction by the grading contractor. BC Rail's engineering, materials management and purchasing departments were responsible for preparing specifications, reviewing tenders and purchasing all major substation equipment. Installation work began May 24, 1983, and the substation was energized on November 7, 1983.

The series capacitor station was supplied and installed on a turn-key basis by one contractor. The station was commissioned and in service in November 1983.

All construction supervision, testing and commissioning was performed by BC Rail.

3.3 Catenary

BC Rail itself undertook the acquisition of catenary system components, ordered from a single manufacturer, in order to take advantage of economies of scale. Purchasing in this manner also

allowed better quality-control inspection during manufacture. All material was delivered to BC Rail's Prince George stores for individual packaging of each pole. BC Rail engineering staff developed a computer program to assist in the sorting of the parts. The program was later expanded for use as a management tool for catenary maintenance.

Construction of the catenary was split into two phases. The first phase involved installing the mast foundations and erecting the masts; the second phase consisted of erecting the catenary.

Half of the mast foundations and masts were erected by BC Rail's maintenance-of-way forces and the remaining half by a local contractor. This work primarily consisted of driving short piles for the foundation, welding the base plate to the pile and erecting and plumbing the pole. A pre-cast concrete base or a drilled, rock anchor base was placed in areas where the pile could not be driven to its design depth. A detailed analysis of the design of the three types of foundation is documented in Reference 4.

Once the poles were erected, the catenary contractors started work on stringing the catenary system. The stringing operation was carried out using a pair of cable reel stands on the back of a flatdeck truck driving along the rail and paying out the cables at a controlled tension. The droppers were then positioned in each span and the cantilevers adjusted for angle when the wire was at full tension. Final adjustments for stagger were then made. This work was done using basic wire stringing techniques.

The contractors completed erecting the catenary system from km 24 to the load-out loops by November 1983, permitting electric operation of the first coal trains on schedule in December 1983. The catenary section from km 24 to the Tacheeda siding, a length of 30 km, was erected by BC Rail in April and May 1984.

This activity provided BC Rail with valuable experience in the construction of railroad catenary systems. Using modified railroad rolling stock, instead of hi-rail mounted highway vehicles, and having direct control over labour and procedures enabled BC Rail to save 35% of the catenary construction costs estimated by contractors. The modified rolling stock is now used for maintenance and new construction.

4. LOCOMOTIVES

Bids for the supply of the electric locomotives were solicited in 1982. General Motors of Canada was selected as the successful bidder, on the basis of the superior sustained tractive effort and performance record of its electric locomotives, designed in cooperation with ASEA Traction of Sweden.

Seven GF6C locomotives were supplied. They are designed to operate as single units or in multiple units of up to six locomotives. Each locomotive is supplied 50 kV AC, 60 Hz power, which is transformed and rectified to a maximum current and voltage of 1042 A, 1115 V DC for the six E88 traction motors in each locomotive. By using thyristor control circuitry, the maximum continuous tractive effort is 400 kN at 34.5 km/h, equivalent to that provided by a 6000 hp conventional diesel locomotive. Advanced radar-based wheel slip detection gives an extremely smooth application of power to the rail.

Each locomotive weighs 180,859 kg and is 20.98 m in length. The locomotives are painted in a distinctive colour scheme of red, white and blue with silver running gear.

The first two locomotives were delivered in late 1983. Testing of locomotive 6001 commenced in November 1983 and ended in March 1984. Most of the tests took place on the Tumbler Ridge Branch Line between km 81.3 and km 84.5. This section of track has a 1.2% compensated grade with curves of up to 6°. A limited number of tests were also performed on a section of track with a 1.5% grade.

General Motors test coach ET840 was coupled to locomotive 6001 to collect the data. The test coach is equipped with multi-channel digital and analogue recording inputs that feed signal processors and a computer. A variety of chart recorders and a printer complete the testing equipment.

The tests performed were primarily aimed at measuring adhesion at constant speeds under various track and environmental conditions. The locomotive and the test car were coupled to three or four conventional diesel locomotives set to operate in their dynamic braking mode to simulate a loaded coal train. Acceleration tests were done with one locomotive, the test coach, and a quarter-sized train of coal cars and later with four electric locomotives, the test coach, and a fully loaded coal train.

Before entering service, the electric locomotives were fitted with an innovative system that remotely controls train speed at loading silos. At other loading facilities, when a train is turned over to the mine for loading, an operator is required on board the locomotive to control the speed of the train during its loading cycle. The remote control system in BC Rail's electric locomotives allows the loading chute operator to directly control the speed of the train, leaving it unmanned during its four-hour loading cycle. The system also features automatic pantograph lowering devices for the non-electrified loading silos and coal adjusting stations.

5. SYSTEM COMMISSIONING

The electrification system was commissioned in phases, upon completion of each of seven subsystems:

1. 230/50 kV sybstation
2. 50 kV feeder line
3. catenary system
4. series capacitor station
5. harmonic filter station
6. SCADA system
7. 50 kV, 240/120 V trackside power supply

Each subsystem was tested and commissioned in two stages. The first stage involved inspecting the unenergized equipment for correct installation in accordance with the manufacturer's drawings and specifications to ensure its safety and reliability in service.

The second stage of commissioning consisted of energizing each subsystem to its rated voltage and testing it for operation. When the energization tests were complete, the equipment was placed into service.

6. POWER MANAGEMENT

In December 1983, with the electrification system largely commissioned and in service, the Tumbler Ridge Branch Line became an operating section of the railroad and was renamed the Tumbler Subdivision. To meet the coal mines' shipping schedules, two trains were put into service. These trains travel northbound, empty from Tacheeda to Tumbler, load at either of the two load-out loops, and then travel southbound loaded from Tumbler to Anzac.

Each train is made up of two electric locomotives, 98 coal cars and a caboose. Each train, when fully laden, has a gross weight of 11,718 tonnes. Helper power is required for the southbound trains from km 98 to km 69, owing to the grade of the track. The helper power is provided by two electric locomotives at the rear of the train.

The rates charged for electricity consumed by the electric locomotives are calculated on the basis of the cost for total energy consumed and a surcharge for peak power drawn over short time intervals (typically a 30-minute period). This surcharge is relatively high compared to the cost for total energy consumed. It is therefore in the interests of the railway to limit surges as much as possible.

To this end, computer simulations using a train performance calculator program were made to create theoretical train schedules and determine "best" and "worst" schedules in terms of operating costs. If trains could be made to run at the optimum schedule at all times, power management would be unnecessary. However, in the real world, this is rarely the case. On the Tumbler Subdivision, schedule variations can occur as a result of delays at loading sites, incidents or maintenance on the line, or incidents or delays on the long trip between Ridley Island at Prince Rupert and the Tacheeda siding. Such variations can create a situation where two trains are climbing grade simultaneously, resulting in increased power demands.

For effective power management, dispatchers must have up-to-date information on energy consumption. BC Rail's supervisory control and data acquisition (SCADA) system provides such data. The system sounds an alarm in the dispatch office when a preset energy demand level is reached. The alarm is set to sound in adequate time for the dispatcher to issue instructions to the trains to reduce demand levels to acceptable values.

When this critical point is close to being reached, the dispatcher or supervisor of operations can decide to adjust the train schedule, based on the excess demand charges for the month and the cost of train delays, crew cost and revenue. The dispatcher has direct radio contact with all trains at all times and can give instructions to any train to turn on the power limit switches in the locomotives to reduce power to an acceptable level.

Power demands are recorded on strip charts for analysis. These charts can be compared to BC Rail's Power Bureau and Train Dispatching records when train operations or schedules require modification for the most cost-effective use of electric power.

7. OPERATING AND MAINTENANCE COSTS

Table 1 presents the costs of operating and maintaining the Tumbler Subdivision using both electric and diesel locomotives in 1984 and 1985. Table 2 gives the net annual savings achievable for various tonnages of coal hauled from 1986 onwards, based on construction costs and operating data collected in 1984 and 1985. The financial summary presented in Table 3 shows that the rate of return on the additional capital required to convert to electric operation is 20.25% without government funding and 62.85% with government funding.

Table 1 Operating and Maintenance Costs for Electric and Diesel Operations, 1984 and 1985

	ELECTRIC	DIESEL	SAVINGS (COSTS)
1984 (5.3 million tonnes — 588 trips)[1]			
Fuel[3]	3,242,000	2,730,000	(512,000)
Maintenance			
Locomotives[5]	1,050,000	700,000	(350,000)
Power Supply & Catenary	495,000		(495,000)
Tunnel Ventilation		220,000	220,000
	4,787,000	3,650,000	(1,137,000)
1985 (7.6 million tonnes — 851 trips)[2]			
Fuel[4]	3,768,000	4,100,000	332,000
Maintenance			
Locomotives[5]	986,000	1,050,000	64,000
Power Supply & Catenary	515,000		(515,000)
Tunnel Ventilation		230,000	230,000
	5,269,000	5,380,000	111,000

[1] 1984 costs in 1984 $

[2] 1985 costs in 1985 $

[3] 1984 fuel costs:
Electric: actual fuel costs in 1984 $
Diesel: prorated based on number of trips - 1984 $

[4] 1985 fuel costs:
Electric: actual fuel costs in 1985 $
Diesel: prorated based on number of trips - 1985 $

[5] 1984 & 1985 locomotive maintenance costs:
Electric: costs include maintenance on the proportionate number of trips with diesel locomotives
Diesel: costs based on the actual number of diesel trips

Table 2 Comparison of Costs for Electric and Diesel Operations for Various Tonnages

	8.5 Million Tonnes per Year (953 trips per year)		13.5 Million Tonnes per Year (1,514 trips per year)		17 Million Tonnes per Year (1,906 trips per year)	
	Electric	Diesel	Electric	Diesel	Electric	Diesel
Capital Cost						
Locomotives[1]	18,386	17,000	26,160	25,500	26,160	25,500
Power supply & catenary[2]	31,420	—	31,420	—	31,420	—
Tunnel ventilation[2]	—	21,700	—	21,700	—	21,700
	49,786	38,700	57,580	47,200	57,580	47,200
Maintenance Cost						
Locomotives	622	1,181	888	1,872	888	2,362
Power supply & catenary	345	—	345	—	345	—
Tunnel ventilation	—	230	—	230	—	230
	967	1,411	1,233	2,102	1,233	2,592
Operating Cost – Energy	1,407	4,596	1,818	7,302	2,105	9,193
Total Maintenance & Operating	2,374	6,007	3,051	9,404	3,338	11,785
Net Annual Savings	3,633		6,353		8,447	

[1] 1983 purchase cost. All other costs are in 1985 $.

[2] Includes interest during construction.

Table 3 Annual Costs/Savings of Tumbler Subdivision
1984-2003 (constant dollars)

YEAR	ADDITIONAL CAPITAL COST		FUEL	LOCOMOTIVE MAINTENANCE	VENTILATION MAINTENANCE	CATENARY MAINTENANCE	TOTAL
	with gov't funding	without gov't funding					
1983	(1,523,000)	(11,086,000)					
1984			(512,000)	(350,000)	220,000	(495,000)	(1,137,000)
1985			332,000	64,000	230,000	(515,000)	111,000
1986			3,189,000	559,000	230,000	(345,000)	3,633,000
1987			3,189,000	559,000	230,000	(345,000)	3,633,000
1988			3,189,000	559,000	230,000	(345,000)	3,633,000
1989			3,189,000	559,000	230,000	(345,000)	3,633,000
1990			3,189,000	559,000	230,000	(345,000)	3,633,000
1991			3,189,000	559,000	230,000	(345,000)	3,633,000
1992			3,189,000	559,000	230,000	(345,000)	3,633,000
1993			3,189,000	559,000	230,000	(345,000)	3,633,000
1994			3,189,000	559,000	230,000	(345,000)	3,633,000
1995			3,189,000	559,000	230,000	(345,000)	3,633,000
1996			3,189,000	559,000	230,000	(345,000)	3,633,000
1997			3,189,000	559,000	230,000	(345,000)	3,633,000
1998			3,189,000	559,000	230,000	(345,000)	3,633,000
1999			3,189,000	559,000	230,000	(345,000)	3,633,000
2000			3,189,000	559,000	230,000	(345,000)	3,633,000
2001			3,189,000	559,000	230,000	(345,000)	3,633,000
2002			3,189,000	559,000	230,000	(345,000)	3,633,000
2003			3,189,000	559,000	230,000	(345,000)	3,633,000
	(1,523,000)	(11,086,000)	57,222,000	9,776,000	4,590,000	(7,220,000)	62,845,000

Rate of return on investment with gov't funding: 62.8495%
without gov't funding: 20.2548%

8. CONCLUSIONS AND RECOMMENDATIONS

The Tumbler Subdivision has proven to be an excellent showcase for 50 kV electrification of a railroad system where heavy tonnages, steep grades, long tunnels and an adverse environment are encountered.

The 50 kV system requires fewer connections to the power grid as compared to the lower voltage systems used in Eastern Canada, the United States and Europe. With the high population densities of these areas, power grids are more closely spaced, allowing for the installation of more substations at shorter intervals to feed a lower voltage catenary system.

These low-voltage systems are not suitable for the sparsely populated regions of Canada. The long distances between main transmission lines would require lengthy feeder transmission lines to service substations. The 50 kV system used on the Tumbler Subdivision requires 25 to 50% of the number of substations needed for a lower voltage catenary.

Only two other 50 kV systems exist in the world today: the 126 km Black Mesa to Lake Powell coal hauling railroad in Arizona and the 860 km Sishen to Saldanha Bay railroad in South Africa. Other potential applications for 50 kV systems in Canada include the Rocky Mountains in Western Canada and the Toronto–Montreal corridor in Eastern Canada.

The information gained from the electrification demonstration has been made available to other Canadian railroads through the Railway Advisory Committee of the Railway Association of Canada, which meets regularly to discuss technological advances in railroad technology. Information is also available through the Transportation Development Centre of Transport Canada. BC Rail's Corporate Information Service has documented the construction of the Tumbler Subdivision on slides and film and in technical papers and reports. A list of references is provided on page 14.

The experience gained in the course of this electrification demonstration has generated a number of recommendations for future electrification projects. These recommendations concern crew training, control and management of equipment parts, and scheduling of catenary work around other grade work.

A comprehensive training course would help workmen to become familiar with the multitude of parts, the most efficient procedure for catenary assembly and the safety precautions to be observed during construction.

Close control of catenary parts is essential, as lost or missing parts can lead to construction delays. A computerized parts program has been developed that can quickly generate a list of the parts needed to build or repair individual poles or sections of poles. The program also provides pertinent data to aid maintenance staff with routine inspections.

Effective scheduling of the many activities involved in the construction of an electrification system is important to avoid conflicts between track or ballasting crews and line stringing crews and ensure the continuity required in each operation.

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